Lightweight, High-Efficiency Pulse Tube Cryocooler

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A lightweight, high-efficiency (LWHE) pulse tube cryocooler (LHEC) has been developed through an Ames, Air Force, and TRW partnership. This cooler is designed to meet NASA's future requirements for zero boil-off (ZBO) propellant storage. Such ZBO systems will meet NASA challenges for developing reusable space transportation vehicles for both Earth-to-orbit and long-duration missions. In addition to ZBO, LWHE coolers can be used with heat exchangers for sizing In-Situ Consumable Production (ISCP) liquefiers for production and storage of propellants and breathable gases during human and robotic exploration missions. Other space applications include a ZBO system for storing liquid nitrogen for shuttle/station astrobiology experiments. As an example, one such experiment stored samples in a 12-liter liquid nitrogen Dewar for periods of up to 12 days. To date, samples required preparation several weeks in advance, necessitating replenishment with liquid nitrogen until loading on the shuttle for launch. A ZBO system would not only alleviate this requirement but would also allow sample storage for longer time periods. Finally, this cooler can be used for Space Science and Earth Science instruments.

The cryocooler is a flight-type pulse tube cryocooler with a design point of 10 watts (W) of cooling at 95 kelvin (K) (–178 degrees Centigrade (°C)). This cooler has an efficiency of 12 W of input power for each watt of cooling at 95 K. This efficiency is nearly a third better than that of the previous design. It weighs 3.6 kilograms (7.9 pounds), about a factor of three less than previous design. The operating lifetime goal of this cooler is 10 years. The cryocooler is shown in figure 1, and the thermal performance of the cooler is illustrated in figure 2.

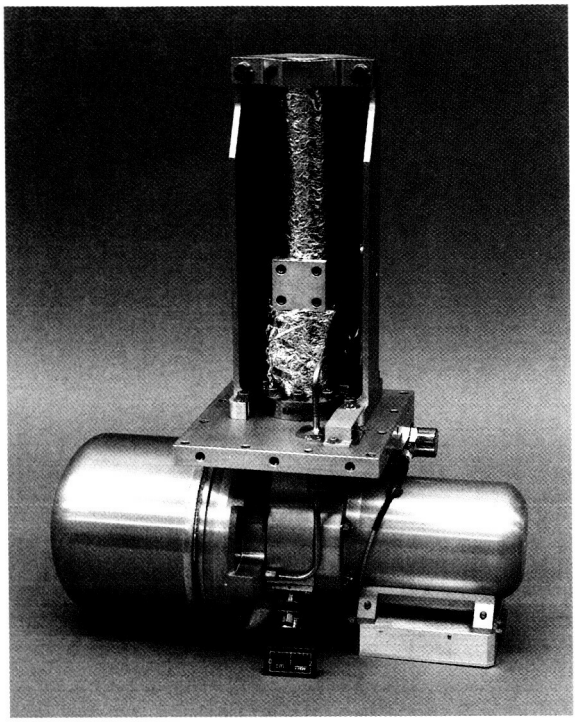

Fig. 1. The lightweight, high-efficiency pulse tube cryocooler. The scale at the bottom is 2 centimeters. The cold plate is the block near the middle of the vertical column.

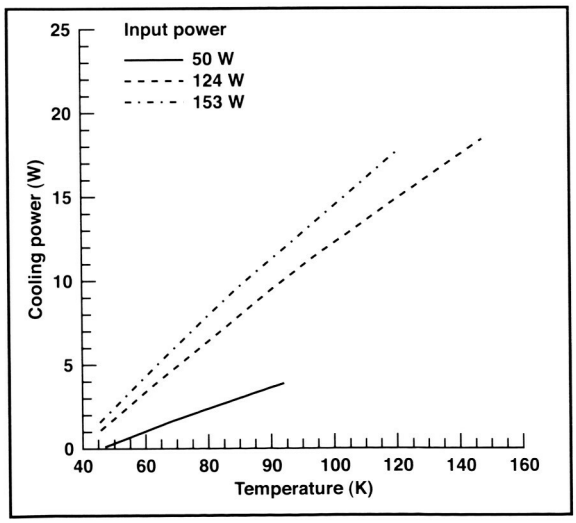

Fig. 2. The performance of the LHEC for three different input powers.

For ZBO space transportation systems, coolers near 95 K are needed for storage of oxygen and methane. Coolers will also be required near 20 K for liquid hydrogen storage. For space applications, less complex coolers such as pulse tubes, which offer the advantage of having no moving parts at the cold head, are presently favored for these cooling requirements from an operating simplicity, reliability, and lifetime standpoint. From a versatility standpoint, 20 K coolers developed for transportation could also be used as first stages for instrument coolers that employ dilution refrigerators or adiabatic magnetization refrigerators as a second stage.

The cooler described here will be delivered to Ames in 2001 for performance testing. Then it will go to Glenn Research Center to be incorporated into a ZBO test in 2002. The ZBO test involves a partnership of three NASA centers: Ames, Glenn, and Marshall. The test will demonstrate the ZBO storage of liquid nitrogen in a 1400-liter (50-cubic-foot) tank.

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Protein Nanotechnology

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Because of NASA's efforts to make missions "faster, better, and cheaper," there is a growing need for the development of smaller, stronger, and "smarter" scientific probes compatible with space exploration. The necessary breakthroughs in this area may well be achieved in the revolutionary field of nanotechnology. This technology is on the scale of molecules, and it holds the promise of creating devices smaller and more efficient than anything currently available. While much exciting research is developing around carbon nanotube-based nanotechnology, researchers at Ames are exploring biologically inspired nanotechnology.

The biological "unit," the living cell, may be considered the ultimate nano-scale device. Cells that are constructed of nano-scale components are extremely sensitive, highly efficient environmental sensors capable of rapid self-assembly, flawless self-repair, and adaptive self improvement—not to mention their potential for nearly unlimited self-replication. Ames is focusing on a major component of all cells (proteins) that are capable of self-assembling into highly ordered structures. A protein known as HSP60, which spontaneously forms nano-scale ring structures (fig. 1a, end view; 1b, side view), that can be induced to form chains (fig. 1c) or filaments (fig. 1d), is currently being studied.

With thermostable HSP60s, highly efficient methods have been developed for purifying large quantities of these proteins; their composition and structure-forming capabilities are being currently modified by using the "tools" of molecular biology. For example, if a small fragment of the HSP60 protein is removed, protein rings are produced that do not form chains or filaments, but continue to form rings that spontaneously assemble into highly ordered hexagonally packed arrays (fig. 2a). If these proteins are modified to bind metal atoms, they can be used as a template to create an ordered pattern of metal on a surface with nanometer spacing. Ultimately the hope is to use such ordered arrays of metal to manufacture nano-scale electronic devices. Similarly,